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ABSTRACT

Methods for the implementation of on-line contingent research are described in this study. In a contingent experimentation procedure, the content of successive experimental trials is a function of a subject's responses to a previous trial or trials (in contrast to traditional experimentation in which the subject is presented a previously established sequence of trials that is constant for all subjects.) Computer control of the sequencing of stimuli on the basis of the subject's responses permits the adaptation of stimulus presentations to the response history of the learner, facilitating the optimization of learning outcomes. The manner in which contingent research designs enable the researcher to examine learning problems that are analogous to the problems of instructional technology is demonstrated, with particular emphasis placed on the implications of contingent research techniques for task management, psychological measurement, and research design. A systematic analysis of contingent decision algorithms and on-line programs is presented, and the application of these programs is examined and compared with non-contingent research designs with respect to procedure, data collection, and efficiency. (Author/MF)

UNIVERSITY OF PITTSBURGH - LEARNING R & D CENTER

TECHNICAL REPORT

METHODOLOGICAL CONSIDERATIONS IN ON-LINE CONTINGENT RESEARCH AND IMPLICATIONS FOR LEARNING

MARNA CUPP WHITTINGTON

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
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PREFACE

I would like to express my gratitude to Dr. William Ray for his thoughtful guidance and assistance throughout this study. Dr. Ray generously gave time and effort to the advising of this research. I would also like to thank Dr. Robert Glaser for his constructive suggestions and frequent communication despite the fact he was a Fellow at the Center for Advanced Study in the Behavioral Sciences in Stanford, California during the writing of much of this paper.

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METHODOLOGICAL CONSIDERATIONS IN ON-LINE CONTINGENT RESEARCH AND IMPLICATIONS FOR LEARNING

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On-line usage of computers in the psychological laboratory opens up new possibilities for research design and measurement. One specific technique that has resulted from the on-line computer capability is the contingent procedure in which a subject interacts with the computer to determine stimulus presentation. In the contingent procedure, a computer presents stimuli in a sequence contingent upon the individual responses of the subject, according to the researcher's procedural design which specifies a finite number of possible stimuli for presentation and decision rules for determining which stimulus is to be presented at each step in the program. Computer control of the sequencing of stimuli on the basis of the subjects' responses permits the researcher much greater flexibility in the management of the research and in the number and complexity of the stimuli presented during the research.

Before this capability can be optimally used in the psychological laboratory, consideration must be given to several important questions. For what research tasks is the contingent procedure suited? For what purposes can the researcher use contingent measurement? How should contingent research be designed?

II. STATEMENT OF THE PROBLEM

Purpose of the Study

The purpose of this study is to investigate methods for conducting on-line contingent research in the psychological laboratory and to systematically explore the implications of contingent research for task management, psychological measurement, and research design.

Description of On-Line Contingent Research

Introduction of on-line contingent research procedures to the psychological laboratory necessitates a re-evaluation of the traditional methods of task management, psychological measurement, and research design. To adequately assess the impact of this new capability its distinguishing characteristics must first be delineated.

1. Presentation of stimuli can be made contingent upon the subject's responses to previous stimuli. The result is continuous adaptation of the stimulus sequence on the basis of the subject's response history.
2. Computer management of procedure provides greater standardization of research. The on-line computer can uniformly administer the entire research procedure according to the algorithm developed by the researcher.

3. Computer management reduces error. The on-line computer collects and records the data while the research is in progress, thereby eliminating human recording and transcribing errors.
4. Computer memory capacities and access times make more quickly available a broader range of stimuli for presentation during research than is feasible with most traditional apparatus. The scope of possible stimuli is increased both in number of stimuli available and range of stimuli available. That is, software developments in interfacing have provided random access audio units, touch sensitive screens, and cathode ray tubes. These interfaces can be used individually or in groups, making possible the simultaneous presentation of audio, visual and tactual stimuli.
5. On-line computers can administer complex research procedures that were previously impossible to implement with traditional apparatus. For example, in verbal recall research Maitland (1970) presented all subjects a 40 word list for recall. On trial 1 the presentation order of the 40 words was constant for all subjects. On the trial 2 presentation each member of the maintained order treatment group was presented the list in the order in which he had recalled them on trial 1. Unrecalled words were randomized and placed at the end of the presentation list. Each succeeding presentation order for the maintained order

group was contingent upon the subject's immediately previous recall.

6. Increased standardization of research procedure reduces error variance and facilitates the detection of effects on the dependent variable (Johnson, 1967).

On-line contingent research procedures that bring the preceding capabilities into the psychological laboratory are controlled by contingent programs written by the researcher. Contingent programs can be classified by the degree of complexity involved in the algorithm for the stimulus sequencing decisions made in the program. The degree of complexity of the algorithm is measured by the number of variables the algorithm considers in determining the appropriate stimulus to present at each step of the procedure. A program classification based on complexity will be outlined here for reference in this study. There is presently no standard classification procedure. Since in many cases program decision types are mixed within programs and are not distinct from program to program agreement among researchers would be difficult to obtain. However, the advantages of having an orderly classification for reference and description purposes offset the disadvantages of the possible disagreement and the inflexibility resulting from a classification.

The three types of contingent programs that are distinguished by the complexity of the stimulus sequencing algorithm are:

a) single stage decision process;

b) multistage decision process; and

c) multistage decision process incorporating extra-program history parameters.

Contingent programs with single stage decision processes have the least complex algorithm for stimulus sequencing. In the single stage decision process only the subject's immediately previous response and not his response history is considered in the stimulus presentation decisions. This decision process can be represented by the function:

$$S_n = f(R_{n-1}) \qquad (1)$$

S_n = stimulus to be determined

R_{n-1} = subject's response to S_{n-1}

n = program sequence number for stimuli and responses

The single stage decision process is easily implemented because the decision algorithm has only one variable. The remaining decision parameters are determined by the researcher before the program is written and are constant across all subjects. For example, in a hypothetical third grade math curriculum there is a program to teach long division by a single stage decision process. In this teaching program, each child receives step-by-step instructions on the long division process and is asked to respond in some manner at each step. The single stage program

responds to his correct or incorrect response appropriately and uses his successful or unsuccessful response to determine the next stimulus presentation. This procedure provides adaptive treatment for each subject on the basis of his immediately preceding response. However, if two students receive frame 6, one after a series of errors and one after a series of correct responses, and both miss frame 6, the first because of lack of knowledge and the second because of carelessness, the single stage program treats them identically because only the wrong response is used in determining stimulus sequencing.

Programs with a multistage decision process involve more complex stimulus sequencing decisions than do the single stage programs. In the multistage programs the subject's entire response history for a program may be considered in the stimulus presentation decision. This decision process can be represented by the function:

$$S_n = f(R_1, R_2, R_3, \ldots, R_i, \ldots, R_{n-1}) \qquad (2)$$

S_n = stimulus to be determined

R_i = subject's response to i^{th} stimulus

n = program sequence number for stimuli and responses

Programs utilizing the multistage decision process vary widely in complexity depending upon how long the program is and how the responses in the program are handled for decision purposes.

If each response made is considered a variable in the decision algorithm, the decision process at frame n would have n-1 variables to consider in the selection of the next stimulus. However, in some programs groups of responses are assigned single values, thus the multiplicity of variables is reduced. For example, in a learning program the first ten frames might constitute a subset of frames within the program which would be assigned a single performance value after the subject had completed all ten. This single performance value would then be used instead of ten single response records in the decision process for later stimuli. In this situation the general function (2) for multistage decision process stimulus determination would be modified:

$$S_n = f(g(R_1, R_2,\ldots,R_{10}), R_{11}, R_{12},\ldots,R_i,\ldots,R_{n-1}) \quad (3)$$

S_n = stimulus to be determined

$g()$= single-valued functional composite of R_1-R_{10}

R_i = subject's response to i^{th} stimulus

Even with this possible simplification, the consideration of more than one previous response greatly increases the complexity of the multistage decision process as compared to the single stage process. For example, if the single stage division program discussed earlier were modified to consider all six of the subject's responses in the stimulus presentation decision, it would be reclassified as a multistage program. In the multistage

version, after the two students missed frame 6 in the teaching sequence they would each have a history file containing six records. Records 1-5 could be any one of 2^5 combinations of incorrect or correct responses. Including frame 6 this makes a possible total of 2^6 different response histories for students completing frame 6. These 2^6 different response histories would be used for the stimulus presentation decision rather than just the correctness or incorrectness of frame 6. Although there may not be 2^6 different and relevant stimulus presentations for frame 7, the increase in complexity of the decision on stimulus presentation is apparent. This increase in decision complexity also provides an increase in flexibility for adaptation of the teaching sequence. Instead of both students receiving the same stimulus 7 as they did in the single stage program, the careless student might be given the next step in the teaching sequence whereas the student genuinely lacking knowledge might be restarted on the program or branched to an easier remedial frame.

The most complex decision procedure is the multistage procedure with extra-program history parameters. In this decision procedure the subject's entire program response history and specified history parameters outside of the program are considered in the stimulus sequencing decision algorithm. The extra-program history parameters are entered into memory prior to the running of each subject. The decision process can be represented by the

function:

$$S_n = f(H_1, H_2, \ldots, H_j, \ldots, H_m, R_1, R_2, \ldots, R_i, \ldots, R_{n-1}) \qquad (4)$$

S_n = stimulus to be determined

H_j = subject's j^{th} extra-program history parameter

R_i = subject's response to i^{th} stimulus

Examples of possible extra-program history parameters are the subject's performance on previous programs, the subject's age, and the subject's ability. Depending upon the number and type of history file variables added to the decision procedure, the multistage decision process with extra-program history parameters can become extremely complex and comprehensive. For example, if the multistage decision process division program discussed earlier were modified to include the subject's IQ, math aptitude test scores, and previous math program scores as variables in the stimulus sequencing decision process, the program would be reclassified as a multistage decision process program with extra-program history parameters.

In this new version of the division program the two subjects previously discussed might not have both received frame 6. The slower student might have an extra-program history containing an IQ of 90, low math aptitude scores, and a record of previous difficulty with math programs. The quicker student might have an extra-program history containing an IQ of 125, moderately high

math aptitude scores, and a record of fast learning on previous math programs. Consequently the slower student would progress through the program in small steps receiving a large amount of stimulus redundancy. The faster student would progress in large steps and possibly skip complete sections of material on which he had demonstrated mastery in preliminary testing.

Presently many of the learning laboratory programs can be classified as single stage decision process or multistage decision process programs. Examples of single stage decision process programs are the branched testing programs in which stimulus decisions are based on the correctness of the immediately preceding response and are independent of early program frames and extra-program history parameters (Bayroff and Seeley, 1967). Examples of the multistage decision process programs are concept formation research programs (Johnson, 1967), verbal learning research programs (Maitland, 1970), and instructional research and teaching programs (Suppes, 1968). Theoretical programs have been developed using the multistage decision process program with extra-program history parameters but few if any of these are implemented yet (Groen and Atkinson, 1966; Karush and Dear, 1966; Smallwood, 1967).

In some single stage and multistage decision programs consideration is indirectly given to extra-program history parameters before the program is run and is not part of the program decision procedure. For example, the pretesting and selecting of subjects

for a specific program by IQ or achievement test scores account for extra-program variables without incorporating them directly in the stimulus sequencing decision procedure.

One reason for not including history files as part of standard decision procedure is the increase in complexity it brings to the program. However, a more important reason is the lack of empirical data on the interaction of extra-program history parameters with the contingent stimuli presented in the program. To use history parameters advantageously and thus benefit from the increased program decision complexity the researcher must nave a detailed knowledge of the relationship between the program objectives and the extra-program information available for each subject. Presently these detailed data do not exist for many types of research. The more general information that is available, for example, on aptitude or age, can be adequately assessed in pre-program selection procedures.

To date, these three decision procedures, the single stage decision process, the multistage decision process and the multistage decision process with extra-program history parameters, are the basic decision procedures used in the majority of contingent programs. However, these three decision procedures do not separate all contingent programs into three distinct classes. Many programs include both single stage and multistage decision processes in the same stimulus sequencing decision algorithm.

History of Contingent Research

Psychophysicists were the first researchers to employ contingent programming in the psychological laboratory. The relatively straightforward nature of the psychophysical research task led to the early implementation of contingent computer programs and facilitated the development of the contingent techniques presently in use. Since the most extensive use of contingent research is still in psychophysics, it is appropriate to discuss in detail the procedures used, keeping in mind that psychophysical research requires less flexibility in the contingent program than does most other contingent psychological research.

The specific tasks in psychophysical research are the determination of absolute thresholds, difference thresholds, and percentage points on subjective response curves, i.e., the values of stimuli that will evoke a specified response on some specified percentage of occasions. For all three tasks the psychophysicist records judgements of varying levels of stimulus intensity and uses these judgements to determine the percentage of responses in each category at each stimulus level. By running enough subjects on an appropriate range of stimulus intensity levels the psychophysicist obtains normative response data which he examines to answer the psychophysical question being explored, i.e., the value of the absolute threshold, the difference threshold, or particular response points of the stimulus being investigated.

In these specific tasks psychophysicists use the contingent procedure to narrow the range of stimuli presented and concentrate observations in the region of the stimulus continuum providing the most information about the question defined in the psychophysical problem. Prior to the implementation of the contingent procedure, psychophysicists explored the entire stimulus continuum, arbitrarily presenting stimulus levels chosen at spaced intervals across the range of possible stimulus intensities.

Two general methods of contingent research in psychophysics are outlined in the following paragraphs. In the examples given a simple yes-no response restriction is imposed to simplify and clarify the discussion of the methods. For example, in a psychophysical task determining the absolute threshold of an auditory stimulus, a "yes" response means the subject heard the stimulus presented and a "no" response means the subject failed to hear the stimulus.

The method of ascending limits, the simplest form of contingent programming in psychophysics, is employed when the psychophysical objective is the determination of specific response percentile points on a stimulus continuum. Each percentile point is determined by the following procedure. An initial stimulus level is predetermined by the researcher and presented to the subject; if the subject's response to this level is "no" the next more intense stimulus is presented; if the subject's response is

"yes" the starting stimulus is presented again. The subject continues to receive stimuli of increasing intensity with each "yes" response and to return to the starting stimulus with each "no" response. By repeatedly approaching the "yes" response intensity from the less intense side of the stimulus continuum, the method of ascending limits focuses on the response percentile point on the stimulus continuum. This method usually involves a single stage decision process, that is, only the previous "yes" or "no" response is used to determine the next stimulus level to be presented. However, a multistage decision process version of this method that utilizes a run of two or more positive responses to terminate the run of increasing response intensity has also been developed.

The up-down transform, a second psychophysical method, is generally used for establishing the value of the absolute threshold on a stimulus continuum. In the up-down transform a "yes" response is the occasion for the next less intense stimulus to be presented and a "no" response is the occasion for the next more intense stimulus to be presented. The stimuli are usually arranged along the continuum in equal steps that have been predetermined by the researcher and calculated prior to the program for the particular stimulus being researched. The up-down transform method has also been modified by replacing the single stage algorithm by a multistage algorithm requiring more than one "yes"

or "no" response to change the direction of the intensity of the stimuli presented.

The method of ascending limits and the up-down transform are both examples of the general methodology of contingent programs used in psychophysics to establish values such as specific response points and absolute thresholds.

A specific program designed by Taylor and Creelman (1967) for psychoacoustical research and called Parameter Estimation by Sequential Testing (PEST) is described in the following pages as it is presently implemented. This description will first outline the stimulus sequencing information that must be built into every contingent psychophysical program and then describe the specific stimulus sequencing features of the PEST program. The goal of PEST is the goal of all contingent psychophysical research: to converge on the selected target level by use of maximally efficient trial-by-trial sequential decisions at each stimulus level.

All contingent psychophysical programs must include four types of information in the stimulus sequencing algorithm (Taylor and Creelman, 1967).

1. Specific rules for determining when the level of the stimulus presented should be changed.
2. Specific rules for determining to what level the stimulus should be changed if the decision has been made in 1) that it should be changed.

3. Rules for terminating the program. (These rules are a function of the amount of error the psychophysicist is willing to tolerate in his data. Without a preset end criterion the procedure continuously approaches the target value in increasingly smaller and eventually infinitesimal steps.)
4. Rules for calculating the target level at the end of the procedure.

In PEST the subject is presented with an arbitrary starting stimulus value and then control of stimulus presentation is turned over to the computer. The following program decision rules satisfy information requirements 1. and 2.

1. On every reversal of step direction, the step size is halved.
2. The second step in a given direction is the same size as the first step.
3. The fourth and subsequent steps in a given direction are each double their predecessor; however, the researcher has an option of placing an upper limit on permissable step size.
4. A third successive step in a given direction is the same as the second if the step preceding the most recent reversal resulted from a doubling of step size; if the step leading to the most recent reversal was not the result of a doubling then this third step is double the second.

In satisfying the third requirement, PEST runs continuously until the decision algorithm calls for a step of some minimum size previously determined by the researcher. The fourth requirement is satisfied by designating the final level of the stimulus presented before the procedure is terminated as the target level.

Taylor and Creelman have used PEST frequently with both naive and experienced subjects using signal amplitude as the independent variable. They have found that the task involved in PEST is easy for the subjects; the contingent procedure is easy to run; and the analysis of the data is straightforward.

The method of ascending limits, the up-down transform, and PEST all demonstrate that the major advantage of contingent programming in psychophysics is the capability of specifying a point or points on the psychometric function without first determining the whole function and then extracting values for the critical points. By zeroing in on a specific point and not exploring informationless stimulus levels all research effort is directed to determining accurate estimates for the points on the response curve that are in question.

Before psychologists could implement the contingent psychophysical methods in psychological research other than psychophysics the methods had to be proven applicable. Two major questions facing the psychologists were: 1) Can the computer effectively administer complex contingent sequences of stimuli

other than the psychophysical stimuli? 2) Are there psychological continua analogous to psychophysical continua and, specifically, can task difficulty be treated as are intensity continuum and be "stepped up and down" effectively? If so, does this capability have any psychological merit? Obviously, a simple yes-no answer is not broadly applicable to either question. However, two important studies in the early stages of the development of contingent psychological research did show the feasibility and merit of computer administration of complex research procedures (Johnson, 1967) and of the process of stepping up and down a continuum of item difficulty (Melaragno, 1967). These two studies are outlined in the following pages.

Johnson (1967) used a concept formation task administered by an IBM 1620 and research assistants to analyze the advantages and disadvantages of computer task presentation. In the task subjects were presented with 32 pattern blocks, four of which are shown in figure 1. The subjects were told that these 32

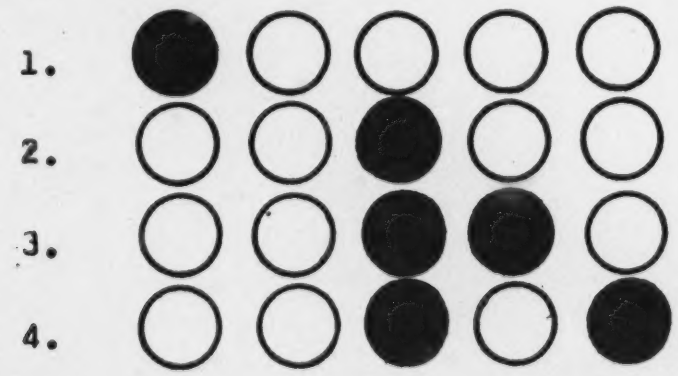

Figure 1. Four Pattern Blocks Used in Johnson's Concept Formation Task

blocks could be grouped into two distinct subsets in a large number of ways; i.e. grouped on the basis of total number of black dots present; grouped on the basis of the color of one particular dot position; or grouped on the basis of a pair of dot positions. The subject was presented one block and its classification as red or green during each frame of the program. After each presentation of a block the subject's task was to hypothesize an appropriate classification rule.

The subject typed his hypothesis on a teletype in the interface language he had been taught at the beginning of the program. His hypothesis was checked for grammatical legality, validity and correctness. Validity was determined by the consistency of the hypothesis with the information the subject had received in previous frames. If the hypothesis was grammatically illegal the subject was asked to retype it; if it was inconsistent the subject was asked to make up another one. If the hypothesis was grammatical and consistent but not correct the subject was presented with a block that would contradict the classification rule he had hypothesized. The decision algorithm always presented the most efficient sequencing of blocks by presenting the subject with a pattern that would refute his current wrong hypothesis. Eventually the subject acquired enough information to grammatically, validly, and correctly induce the proper classification rule.

Johnson presented this procedure to each subject twice, once administered by a research assistant and once by an IBM 1620, to explore the differential presentation effects.

Johnson's results showed that the mean performance did not differ significantly in the two presentation conditions. However, the variance in performance in the computer administered condition was reduced. Johnson attributes this difference to a reduction in error variance resulting from the automation of the research procedure. Johnson states that this reduction in variance is particularly significant because it implies that computer-administered research should be more sensitive to independent variable manipulations because main effects are less apt to be masked by error variance. Johnson's data also showed that the IBM 1620 outperformed the research assistant in assessing the validity of the subject's hypothesis and in selecting the next pattern for presentation.

Johnson's results favor the implementation of contingent programs in the psychological laboratory for task management and procedural reasons. His study empirically demonstrates the feasibility of computer administration of complex contingent sequences of stimuli.

Melaragno (1967) used three versions of an instructional program for geometric inequalities as treatments in an experiment to compare the effectiveness of adaptive and non-adaptive teaching

procedures. The three treatments were a linear program, a branched program, and a prediction program. The linear program, as the control program, was not contingent, that is, it presented the same set of stimuli to each subject regardless of his entry behavior and his program performance. The branched program was contingent in that it altered the instructional sequence on the basis of the correctness of the subject's responses. The branched program treated the item difficulty continuum as a psychophysical continuum and stepped up and down it, adapting the difficulty of the item presented on the basis of the correctness of the subject's responses. The prediction program pretested the subject's entry behavior and routed the subject to the appropriate form of a linear program on the basis of the subject's pretest score.

Melaragno's study was conducted in two phases. In the first phase, empirical trials of self-instructional programs were carried out to assess the value of branching logic and to determine the appropriate branching strategies and program frame sequences for each treatment program on the specific subject matter, geometric inequalities, used in the study. The second phase of the study, conducted in a computer-based instructional laboratory, presented the linear, branched and prediction programs developed in phase 1 to the subjects and assessed the relative effectiveness of the three methods of instruction.

In the first phase, thirty-two high school students were

administered seven pretests and the developmental program. The developmental program consisted of six units: units 1-5 covered theorems, axioms and postulates for geometric inequalities; unit 6 taught proof of theorems. At the end of each of the six instructional units, the subjects were given a quiz on the material covered and a discussion section on the questions and appropriate answers for the quiz just completed. Detailed performance records were kept for each subject to determine specific program locations that needed remedial instruction and specific sequences that should incorporate larger steps for the more able students. The posttest for the program consisted of 57 points: 29 points for tasks directly related to the content of the program; and 28 points for tasks related to transfer situations.

From these data a final program was developed that consisted of 248 teaching items, 20 testing items, and 38 remedial items. The subjects' seven pretest scores were evaluated in relation to their posttest scores and these data were used to establish assignment rules for the subjects in the prediction group.

In the second phase of the study, the geometric inequalities program developed in phase 1 was used to evaluate the three types of instruction. A total of forty-four high school students were randomly assigned to the treatment conditions. The experiment had a completely randomized design with three groups. The three types of instruction were the treatments and the scores on the

posttest and the training times were the dependent variables.

The linear program treatment group received the 248 main instruction items, 20 quiz items, and 17 remedial instruction items.

The branched program treatment group progressed through the program with all branching decisions made on the basis of their prior performance and their quiz scores at the ends of the previous units.

The prediction program treatment subjects each received a linear program judged appropriate for them on the basis of their pretest scores.

Melaragno's results showed a significant ordering of the three treatment groups on the basis of posttest scores. The branched treatment was the most effective, the prediction treatment next, and the linear treatment least effective. The training times showed that the branched instructional program produced superior posttest scores with a significant savings of time.

The performance of the subjects in the branched treatment group empirically demonstrated the feasibility and merit of implementing contingent procedures in the research of psychological continua. As in psychophysics, the branched treatment procedure saved time and produced comparable or better results when compared with the linear procedure.

Johnson and Melaragno's studies have provided positive answers to the two questions of feasibility: 1) Can the computer effectively administer contingent sequences of complex stimuli? and 2) Can a psychological difficulty continuum be considered analogous to a psychophysical continuum and be treated as a psychophysical continuum? The implications of implementation of on-line contingent procedures in psychological research will be considered for task management, psychological measurement, and research design.

III. IMPLEMENTATION OF ON-LINE CONTINGENT PROGRAMS IN THE PSYCHOLOGICAL LABORATORY

The primary purpose of this study is to explore possibilities for the conduct of on-line contingent research in the learning laboratory. Information on both contingent programs and on-line usage of computers in laboratory research has been presented. The discussion will now focus on the primary question - What possibilities are there for the additional use of on-line contingent programs in the psychological laboratory?

Several characteristics of on-line contingent programs should be specifically recalled and considered when answering this question. First, in this type of research subjects are treated as individuals who may respond alike when treated differently and differently when treated alike. No attempt is made prior to the beginning of the research procedure to fix the series of stimuli they should receive. After all the subjects have completed the contingent program, each can be assigned a track number that represents the set of stimuli he received during the program. If the researcher chooses, in his data analysis all subjects following the same track through a program can be considered as a group or supply defined for further research.

A second unique characteristic of on-line contingent programs

is the procedure used in stimulus sequencing. The presentation of stimuli is determined by the subject's responses. Thus different subjects may receive different stimulus sequences and differing total numbers of stimuli. Unlike traditional research designs that present a constant number of stimuli to all subjects in the same treatment group, the contingent procedure makes no attempt to equate the number of stimuli presented to each subject. With these two unique characteristics to consider, a study of the possible applications of contingent research procedure to psychology was carried out.

The implications of on-line contingent programs will be considered in three phases of psychological research: 1) task management; 2) measurement; and 3) design. As Uttal (1969) states, "the truly automated laboratory is in its early stages of development" so there are few published examples of the new techniques and the research that is in the literature is not completely developed or analyzed.

Task Management

The nature of the task in psychological research is determined by the problem outlined by the researcher. Since the specific task involved in the research problem determines the applicability of on-line contingent procedure to task management,

three specific kinds of tasks frequently studied in the learning laboratory have been selected for examination: 1) discrimination learning tasks; 2) transfer learning tasks; and 3) concept formation tasks.

Discrimination Learning Tasks

Discrimination is operationally defined as responding differentially to different stimuli. In an empirical sense discrimination is the opposite of generalization and discrimination learning is the process of breaking down generalizations.

Discrimination learning is usually a gradual process taking place over a number of trials that serve to orient the subject to the relevant features of the stimulus. If the subject does not attend to the discriminative features he will not obtain the information necessary to solve the discrimination problem.

The general method required to produce a discrimination involves the simultaneous extinction of generalized responses by non-reinforcement and strengthening of the discriminative response by reinforcement. Two traditional research techniques are used to accomplish this task: 1) the method of successive presentation of stimuli; and 2) the method of simultaneous presentation of stimuli (Kimble, 1961).

In the method of successive presentation of stimuli only one stimulus is presented on each trial - either the stimulus requiring and reinforcing a response (the positive stimulus)

or a stimulus requiring no response (the negative or generalized stimulus).

In the method of simultaneous presentation of stimuli the positive and the negative stimuli are presented together and the subject must respond to the positive stimulus.

In what manner can the contingent procedure be applied to these discrimination task procedures?

The contingent procedure can be used to incorporate stimulus shaping techniques in discrimination learning tasks.

In non-contingent discrimination tasks the stimulus shaping technique attempts to teach subjects an errorless discrimination by beginning with a very easy discrimination and presenting a series of progressively more difficult discriminations. The final discrimination in the series is the discrimination traditionally presented throughout a standard simultaneous presentation procedure. In the stimulus shaping procedure the positive stimulus in the initial easy discrimination remains constant and is reinforced for all succeeding discriminations in the series. The negative stimulus in the initial discrimination is a highly discriminate version of the final negative stimulus in the stimulus response relation the researcher is trying to teach. The non-contingent stimulus shaping procedure gradually shapes the initial negative stimulus until it is identical to the negative stimulus in the discrimination task being taught. The step sizes in the shaping sequence are those judged most facilitating for the

majority of the subjects. The step sizes are predetermined by the researcher and are constant for all subjects. The stimulus shaping procedure attempts to have every subject practice and master each discrimination in the shaping process and discriminate the final step with no errors.

The merits of the stimulus shaping procedure are demonstrated by an experiment done by Sidman and Stoddard (1967). Sidman and Stoddard presented nineteen retarded boys with a circle-ellipse discrimination task. The control group received a traditional simultaneous presentation of stimuli program to teach the discrimination; the experimental group received a stimulus shaping program. The results showed a significant difference in the performance of the two groups. In the control group, only one of the nine subjects learned the discrimination. However, in the experimental group seven out of ten subjects learned to discriminate between the circle and the ellipse. This data clearly supported Sidman and Stoddard's hypothesis that the stimulus shaping program could teach the retarded students more effectively than could the traditional discrimination learning program. Similar results have been shown for normal children (Hively, 1962; Holland and Matthews, 1963; Moore and Goldiamond, 1964; Suppes and Ginsberg, 1962 a, 1962b).

The implementation of efficient stimulus shaping programs for discrimination tasks is hampered by two recurrent problems:

1. The same step sizes in the stimulus shaping sequence are not equally effective for all subjects. Some subjects can learn the discrimination with large shaping steps while others require very small steps.
2. Subjects require differing numbers of practice trials on each step of the stimulus shaping procedure to ensure mastery of that step.

In a contingent stimulus shaping procedure, the step sizes in the stimulus shaping process and the number of practice trials on each step could be individualized. By making the presentation of stimuli contingent on each subject's responses and response latencies, the contingent shaping procedure could ensure that each subject would receive the stimulus sequence most suited to his learning capabilities and would master each discrimination step before progressing to a more difficult discrimination.

The contingent capability of efficiently teaching an error-less discrimination task has important practical application in the individualization of instruction now receiving much attention from educators and in the teaching of students previously incapable of learning from traditional training procedures.

Transfer Learning Tasks

The transfer of learning problem is the study of the interference or facilitation of previous learning on new learning.

There are two basic research designs for transfer studies: 1) the proactive design; and 2) the retroactive design. Both designs require two groups of subjects.

In the proactive design group 1 practices task A and is tested on task B; group 2 rests while group 1 is practicing task A and is tested on task B also. The difference in the performances of groups 1 and 2 is attributed to the transfer of learning from task A to task B.

In the retroactive design group 1 practices task A, practices task B and is tested on task A. Group 2, the control group, practices task A, rests, and is tested on task A. The difference in the performances of groups 1 and 2 on task A retest is attributed to the interpolated practice on task B.

In what ways can the contingent procedure be used in transfer of learning research?

In transfer of learning tasks, the contingent procedure allows the researcher the flexibility of choosing task B contingent upon the subject's performance in task A. When subjects receive the same physical stimuli the effect of the stimuli may differ from subject to subject. It is also true that subjects receiving different stimuli may respond the same. In contingent transfer learning procedures task B can be adapted on the basis of subjects' differing responses to a constant task A.

A summary of "Transfer Effects in Whole/Part Free Recall", a verbal recall experiment done by Tulving and Osler (1967), is presented below. A proposed revision that incorporates a contingent decision procedure to modify task B on the basis of the subject's performance on task A follows the description of the traditional transfer of learning design.

Tulving and Osler examined the transfer effects in list learning tasks and the implications of the transfer effects for two current contradictory verbal learning hypotheses. The first hypothesis, the independence hypothesis, is that recall of a given item on a list is not influenced by recall or non-recall of any other item or items on the list. The second hypothesis, the interdependence hypothesis, is that words are organized into higher order memory units and recall of a word is greatly influenced by recall or non-recall of other words in that unit.

The design of Tulving and Osler's experiment was a 3x2 factorial. Each of the six groups of subjects learned two lists of nouns: the first list consisting of 18 words; and the second list consisting of 9 words. The first factor in the experiment was three levels of practice on the first list: 6 trials; 12 trials; and 24 trials. The second factor was the list relationship. The three experimental groups received a second list composed of 9 words randomly selected from the first list. The three control groups received a second list composed of 9 new

nouns.

Tulving and Osler's results showed a significant negative transfer from task A to task B for the three experimental groups.

If Tulving and Osler's experiment were rerun with a contingent decision procedure, the choice of words in the experimental group's second list could be made contingent on their performance on the first list. By defining rules for choosing list 2 rather than specifically predeterminimg each item, specific transfer situations could be established for each subject on the basis of his performance on task A.

For example, to examine the validity of the two hypotheses a series of four experiments identical in format to Tulving and Osler's could be run. In each experiment the experimental and control groups would receive the same task A, a list of 18 words to recall. Task B for the control group would be a list of 9 unrelated words. Task B for the experimental groups would be defined by a set of rules for choosing 9 items from list 1 on the basis of the subject's performance on task A.

Experiment 1: A list composed of the 9 words the subject learned first in task A.

Experiment 2: A list composed of the 9 words the subject learned last or failed to learn in task A.

Experiment 3: A list composed of the 9 words most often appearing together in the recall protocols of the subject during task A.

Experiment 4: A list composed of the 9 words least often appearing together in the recall protocols of the subject during task A.

In each of the experimental groups the items presented in task B are contingent upon the subject's performance on task A. Thus the subjects within an experimental group would receive different stimuli on the basis of their past performance. However, all the stimuli presented to subjects within a treatment group would share a defined characteristic relevant to a specific transfer problem. By adapting task B items for each subject, the researcher is able to present to every subject within a treatment group the same transfer situation.

These are just a few of the possibilities for contingent experiments to explore the transfer process in recall. This contingent technique has important implications for transfer of learning research because it permits the researcher to eliminate from his data some of the "effect noise" to which Smith (1967) referred and to explore separately each facilitating or interfering characteristic of a task in a transfer of learning study.

Concept Formation Tasks

Concept formation tasks require the subject to learn and apply a definitive set of properties. A concept is defined as "a class or category all the members of which share a particular combination of critical properties not shared by any other class" (Markle and Tiemann, 1970). Persons who have learned a concept need not be able to verbalize it but must be able to discriminate non-members of the class from members of the class. Thus discrimination and identification are the basic operations in concept learning.

There are generally two methods used in concept formation problems: 1) identification method; and 2) response method.

In the identification method the subject is usually presented with the entire sample of stimuli and asked to choose one from the sample. The researcher then tells him whether the one he chose is an example of the concept. The subject continues picking objects until he has chosen a long string of correct choices (the number needed is the preset criterion for concept attainment).

In the response method the subject is given a stimulus and he must name the concept. The subject guesses at a name and the researcher tells him right or wrong and supplies the correct name. The researcher continues presenting stimuli to the subject until he has a long series of successes at naming the concept

represented by each stimulus presented.

In what ways can the contingent procedure be applied to concept formation research?

The contingent procedure can be used in concept formation tasks to present the most efficient stimulus sequence for concept learning to each subject. If the stimulus presented were made contingent upon the subject's previous response, a stimulus contradictory to the most recent hypothesis could be presented at each trial. A contradictory stimulus would provide the subject maximal possible information about the correctness and incorrectness of his present hypothesis.

For example, in Johnson's (1967) experiment outlined on pages 18-19, contingent stimulus presentation is used with pattern blocks. In this experiment, the subjects were presented 32 blocks and told the blocks could be grouped into two distinct subsets in a large number of ways. The subjects were presented one block and its classification as red or green during each frame of the program and their task was to hypothesize the appropriate classification rule. If the subject's hypothesis was incorrect he was presented a block that would contradict the classification rule he had proposed. An example of a stimulus response sequence for an easy concept formation task is outlined on the following page.

Stimulus 1: Green

Hypothesis: Green blocks have the first dot black.

Stimulus 2: Red

Hypothesis: Green blocks have one dot black.

Stimulus 3: Green

Hypothesis: Green blocks have the odd dots black.

Stimulus 4: You are correct. Green dots do have the odd dots black.

By presenting the blocks contingent upon the subject's most recently hypothesized concept the program provides an efficient sequence of frames that provides maximal information about the correctness and incorrectness of the subject's recent response.

The incorporation of the contingent stimulus presentation procedure reduces the complexity of the traditional concept formation task. The contingent procedure presents only those stimuli relevant to the dimensions or concepts on which the subject is presently focused and not a confusing sample of the entire population of stimuli available. This contingent

procedure offers the learning researcher a more effective technique for teaching concepts that have traditionally been time consuming and difficult for the students.

Measurement

The methods for using the contingent procedure in psychological measurement are determined by the researcher's application of the resultant measure. There are three basic applications for contingent measurement:

1. placement of subjects on a psychological continuum;
2. classification of subjects into supplies for description or further research; and
3. assignment to subjects of a classification score predictive of other variables with criterion status.

The contingent measurement procedure, often referred to as a branched or tailored test, was developed from the psychophysical testing procedure by treating the psychological continuum of the parameter to be measured as a psychophysical continuum of stimulus intensity. As in psychophysics, the contingent measurement procedure reduces measurement time by focusing on frames most informative about the subject.

The first application of contingent measurement is the placement of subjects on an evaluative continuum. Bayroff and Seeley(1967)

at the U. S. Army Behavioral Research Laboratory did some of the early work in the development and application of contingent measurement procedures for the placement of subjects on verbal and mathematical aptitude continua. They compared on-line contingent tests and conventional paper-and-pencil tests with respect to reliability, information conveyed by the test score, and test construction rationale. For the study, Bayroff and Seeley constructed verbal ability and arithmetic reasoning branched tests with items selected from the experimental forms of the Armed Forces Qualification Tests, AFQT 7-8 and AFQT 5-6. The verbal ability test was an 8 item test designed as a counterpart to the traditional 40 item test in the Army Classification Battery; the mathematical reasoning test was a 9 item test designed as a counterpart for the traditional 30 item test. Each test plan had a pool of items ranging in difficulty from p=.25 to p=.95. Examinees who reached and successfully answered the most difficult item p=.25 were given an additional item of difficulty p=.20 to increase the test ceiling. The four-alternative multiple choice items were expanded on the branched test to include two additional wrong choices to reduce the chance of correct guessing. The test item plan is shown in figure 2.

One hundred and two enlisted men from Fort Belvoir, Virginia took the two branched tests on the teletype and the two paper-

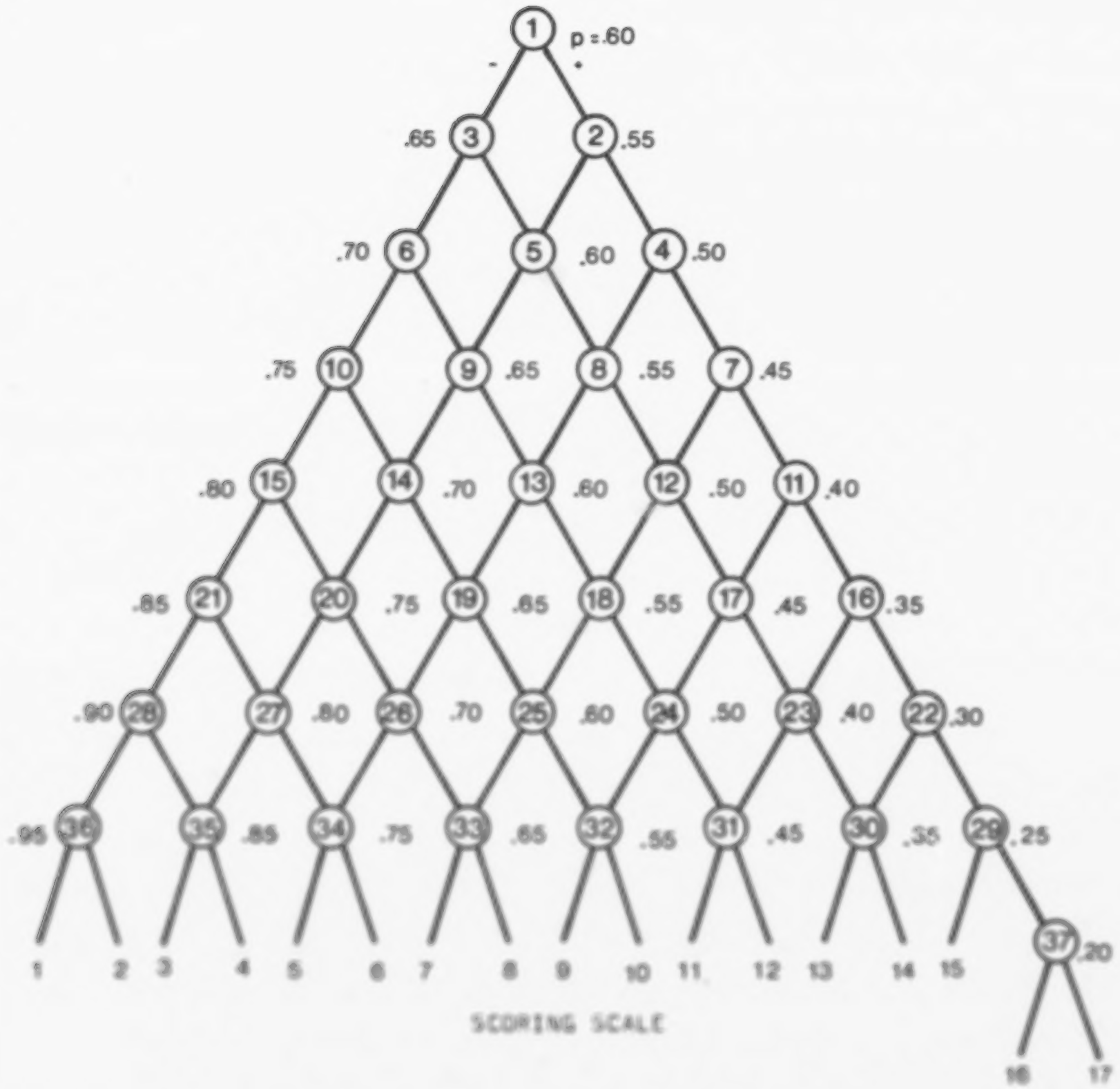

Figure 2: Branching Test Plan for Containment Measurement

and-pencil linear tests in counter-balanced order, half taking the two branching tests first and half taking the two linear tests first. The linear tests were scored in the traditional manner and the branched tests were scored according to the relative difficulty ratings of the last frame presented in the test.

In analyzing the scores of the linear and contingent tests Bayroff and Seeley found a correlation of r=.78 between the verbal ability tests and .74 between the arithmetic reasoning tests.

The test-retest reliabilities for the branched tests were computed as r=.76 for the verbal and .73 for the arithmetic. Since a previous study had established the test-retest reliability of the linear verbal and arithmetic tests at r=.91 and .85 respectively the reliabilities of the 8 and 9 item branched tests were nearly the maximum that could reasonably be expected. Using the Spearman-Brown formula, Bayroff and Seeley calculated that a linear test would need 16 items to achieve the reliability of the branched test for verbal ability and 19 items to achieve the reliability of the branched test for arithmetic reasoning.

In this study Bayroff and Seeley have demonstrated empirically the validity, reliability and time-saving feature of the contingent procedure in placing subjects on the psychological

continua of mathematical and verbal aptitudes.

The second application of contingent measurement programs is the classification of subjects into supplies for description or further research procedures. Traditional research designs often call for matching of groups or homogeneous supplies of subjects. The contingent measurement program can be used to efficiently assess the matching characteristics of each subject and assign subjects tracks on the basis of these characteristics. After all the subjects have been contingently measured, those following the same track can be used as matched subjects.

Ferguson (1970) developed and implemented one of the first contingent tests for classifying students for placement in a math curricula of individually prescribed instruction. Ferguson's contingent test was designed to determine if the subject had or had not mastered each of the 18 objectives in the Addition-Subtraction math unit. Mastery or non-mastery for each objective was assessed contingently by taking advantage of the Guttman-type hierarchical task structure, figure 3, that was established among the objectives in the unit. When a subject demonstrated mastery of one of the objectives in the hierarchy the program inferred mastery of all the objectives prerequisite to it.

Ferguson's contingent measurement program tested or inferred the subject's mastery on each of the 18 objectives and classified the subject on the basis of the objectives for which he had

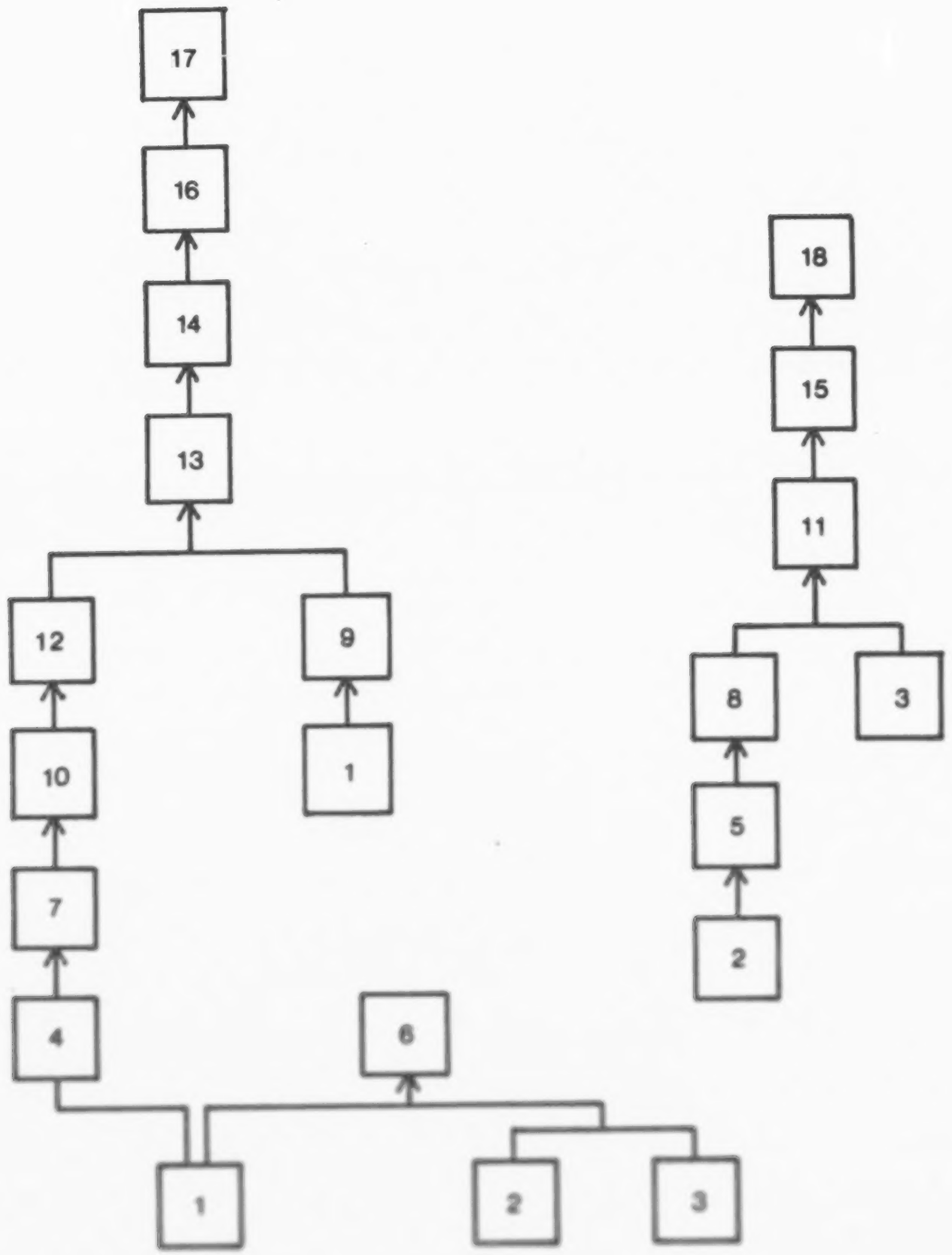

Figure 3: Hierarchy for Addition-Subtraction Objectives

demonstrated mastery. This classification was used to place the subject at the appropriate place in the individually prescribed instruction curriculum.

Ferguson's program made two types of contingent measurement decisions:

1. whether a subject had or had not mastered a specific objective; and
2. what sequence of objectives should be tested for mastery.

The first type of decision, determination of proficiency or non-proficiency in a specific objective, was made by presenting randomly selected items of equal difficulty until the decision algorithm had enough information to infer mastery or non-mastery of that objective. The decision algorithm assumed that the subject had the same probability of success on each item presented; that the response to any given item was independent of the response made to the previous item; and that the subject's score on the items presented was an adequate estimate of his proficiency on the objective.

Once a decision was made about the subject's proficiency on one objective, a decision had to be made regarding the objective to be tested next. The task hierarchy in the Addition-Subtraction unit was divided into the seven scales shown in figure 4. Each scale is composed of a group of objectives which are sequenced such that starting from the left, each objective

is the prerequisite of all objectives to its right. The branching algorithm for the sequencing of objectives used these scales. Testing for all subjects began with objective 12 of scale 1. If the subject demonstrated mastery of this objective he was branched to either objective 14 or 17 depending on how many errors he had made in the set of frames presented for objective 12. This branch and test cycle continued until a decision had been made about each objective on the scale.

Scale	Objectives Comprising the Scale	Coefficient of Reproducibility for Scale
1	1, 4, 7, 10, 12, 13, 14, 16, 17	.995
2	1, 9, 13, 14, 16, 17	.992
3	1, 6	1.000
4	2, 6	.997
5	3, 6	.960
6	2, 5, 8, 11, 15, 18	.999
7	3, 11, 15, 18	1.000

Figure 4: Scales of Objectives for the Contingent Sequencing Procedure

The results of the branch and test cycle provided the information needed to place students at the appropriate point in the math curriculum. It eliminated repetition of previously learned objectives and ensured mastery of all necessary prerequisite material.

In some research situations the contingent procedure for classification of subjects is longer and more difficult to implement than traditional matching procedures. In each case, the researcher must decide whether the adaptive testing features and the high validity and reliability provided by the contingent procedure merits the increased effort and time required for implementation. In the study discussed, Ferguson developed the testing program for incorporation into an academic curriculum. The continuing use of a contingent measurement procedure to increase efficiency of a teaching sequence for every student receiving a specific unit in mathmatics would seem to merit the increased time required for development.

This contingent procedure is applicable wherever the researcher needs to match subjects and can determine the relevant dimensions for matching or wants to appropriately place subjects for further research and can pinpoint the relevant criteria for placement.

The third application of contingent measurement programs is the assignment of subjects to classes that are predictive of some other variable of criterion status. Johnson (1969) did one of

the first contingent measurement studies in which a subject's performance on a contingent task could be used to predict the subject's performance on a standardized test.

In his study Johnson gave the subjects a concept formation problem to solve. By making the solution to the problem contingent upon the subject's responses he was able to maximize trials to correct solution for each subject and thus maximize the information collected on each subject's concept formation process.

When Johnson analyzed the subjects' solutions he found that the subjects could be classified according to their solution methods.

1. Strategic group - characterized by methodical and predictable solutions.
   a. Scanners - a subset of the strategic group characterized by their taking many trials in a short period of time
   b. Focusers - a subset of the strategic group characterized by their taking a few trials in a long period of time
2. Tactical group - characterized by non-methodical and non-predictable solutions
3. Mixed Group - characterized by non-strategic and non-tactical solutions

Johnson compared these three groups on SAT scores. He found that the strategic group out-scored the tactical group by 50 points on the verbal test and 90 points on the math test. Within the strategic group, the scanners and focusers performed the same on the math test but the scanners performed 65 points better than the focusers on the verbal test. By running subjects on this contingent concept formation task and classifying them according to their methods of problem solution, Johnson could use each subject's classification to predict his SAT scores.

Johnson's research procedure does not provide the best method for predicting a subject's SAT scores. However it does demonstrate the use of a contingent procedure for assigning subjects to classes that are predictive of another variable of criterion status. Very little research has been done in this area of contingent psychological research. The possibilities for this method of prediction of variables are numerous.

IV. SUMMARY AND CONCLUSIONS

This study has focused on methods for the application of on-line contingent research procedures to psychological task management and parameter measurement. The new research designs made available by the contingent stimulus presentation capability are the primary advantage of the implementation of contingent research procedure. These contingent designs enable the researcher to apply treatments and collect data unavailable with traditional research techniques. Concomitantly increased standardization of research due to computer administration and the time-saving feature of the contingent technique contribute to making the on-line contingent research procedure an attractive alternative to traditional research designs for some types of psychological research.

The success or failure of contingent research depends upon the design of the program decision algorithm. Traditional research procedures are designed to present the same predetermined sequence of stimuli to all subjects within a treatment group and to make no allowance for treatment-subject interaction. The variance in the data resulting from treatment-subject interaction is usually included as part of the error variance in the experiment. In contrast, contingent research procedures are designed to present

adaptive sequences of stimuli to each subject. By adapting the stimuli presented the contingent procedure maximizes treatment-subject interaction. Consequently traditional research designs are incompatible with the goals of contingent procedures. How then should the contingent programs be designed? If the contingent procedure is to individualize the treatment of each subject in a meaningful way each stimulus decision in the contingent program must be established empirically and must be tested for validity and reliability. By using a traditional experimental design, the researcher must determine the treatment-subject response patterns for all possible supplies of subjects at each node of the contingent program and empirically derive each branch. Contingencies cannot be developed by intuition or guessing. Each contingency must be established in the context of the program with the population for which the program is designed. The value of contingent research data rests on the assumption that the branches made within a program for a given subject are meaningful and the contingent data resulting from the program are in fact representative of the subject. Establishing the contingencies is a time-consuming tedious task but the comprehensive data produced by a sound program provide the researcher information about treatment effects, psychological processes, and treatment-subject

interactions that is unavailable with traditional research designs.

This study is in no way suggesting a complete switch from traditional research procedures to contingent research procedures. The traditional design is not only necessary in the establishment of contingencies for the response contingent designs but it is also an important research tool. A substantial portion of psychological research is done well with traditional techniques and contingencies have no meaningful place in the design. However, this study does suggest that for some types of research the flexibility of the on-line contingent procedure will allow the capability of performing valuable research previously impossible to conduct with traditional techniques. Before implementing the contingent procedure the researcher must assess the relative advantages and disadvantages of the two procedures for the goals and operations of his research. The addition rather than substitution of the contingent procedure in the psychological laboratory should provide the researcher a powerful combination of research procedures for more intensive and extensive psychological research than was previously feasible.

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APPENDIX A

The multiplicity of shades of meaning assigned to the following terms in the literature necessitates the inclusion of the precise definition used in this methodological analysis.

Algorithm: Webster's Seventh New Collegiate Dictionary defines an algorithm as "a rule of procedure for solving a recurrent mathematical problem". In contingent research an algorithm is defined more specifically as a step by step procedure for making program branching and stimulus presentation decisions. The algorithm is the decision-making or logical component of the contingent procedure developed by the researcher for the computer and characterized by two properties:

1. It is deterministic in that it specifies an exact procedure to be followed at each step of the program.
2. It is general in that it specifies an exact procedure for any and all subjects.

Branched Test: (Also called tailored test or sequential-item test) A branched test presents each subject with only those questions that are most informative about his level of competence in a specific skill or content area. The branched testing technique achieves individuality by presenting an easier

item after each failure by the subject to respond correctly and presenting a more difficult item after each successful correct response. This process of stepping up and down the difficulty scale theoretically seeks the achievement level of each subject.

The branched testing procedure was developed from the psychophysical testing procedure by analogizing the question difficulty scale to the stimulus intensity scale.

Contingent: Contingent refers to the characteristic of branching on the basis of a subject's immediate response, response history or extra-program history.

History: (Also called history file) A history is recorded for each subject run on a contingent program. The history provides a record of all information necessary in the program decision making including:

1. the information initially entered in the computer on each subject, for example, age, grade or sex.
2. the cumulative record of all previous subject responses on the program; and
3. the record of all previous decisions made about the subject on the program.

On-line: On-line refers to the interactive computer as the presentation mode of a program.

On-line Contingent Program: A generalized schematic of an on-line teaching program is drawn below. The features of this schematic are explained in the next four definitions.

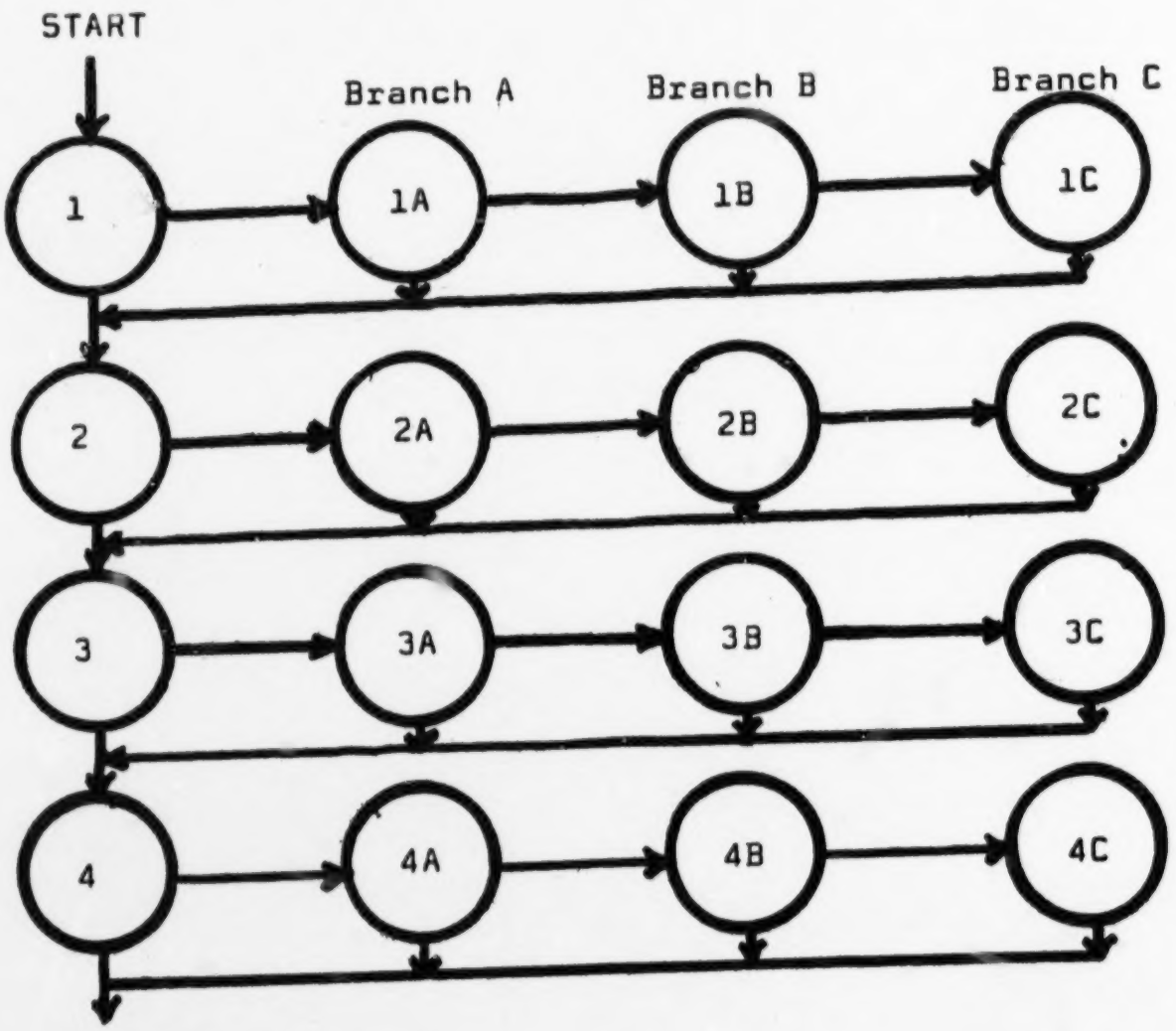

Figure 5: Generalized Schematic of an On-line Contingent Teaching Program

Frame: A frame, the smallest component of an on-line contingent program, is defined as initiated when a decision is called for regarding which stimulus is to be presented next in the program and terminated when the history is updated with a record of the response made to that stimulus.

In the schematic, groups of frames are represented rather than single frames. Nodes 1-4 on the unbranched track, nodes 1A-4C on the branched track and all the internodal teaching sequences are groups of frames.

Node: A node is a decision point in a contingent program at which a subject may progress in one of two or more different directions. In the schematic, the labeled circles represent the nodes. At each of these nodes the subject's responses to a series of frames determine on which of the two alternative paths he will proceed. For example, at node 1 the subject's responses determine whether he will progress vertically to node 2 (in the direction of mastery) or horizontally to branch 1A (for remedial work on the same level as the frames just completed).

Branch: A branch is a sequence of content and decision frames supplementary to the core sequence of content and decision frames. In the schematic of the teaching program, the

remedial teaching sequences and decision nodes extending horizontally from the vertical linear path (nodes 1-4) are branches. In contingent teaching programs a branch is the vehicle for providing the student with adaptive tutorial instruction based on his previous responses rather than informing him simply of the correctness or incorrectness of his responses.

Track: A track is the unique set of stimuli presented to a specific subject in his progress through a contingent program. A subject's track consists of each and every frame presented to him from the initial stimulus to his terminal response.

In the schematic of the contingent learning program, a subject's track would be designated by: each teaching frame he received and his response to it; each nodal frame he received and his response to it; and each program decision made. From the schematic, it is evident that subjects may follow any one of a large number of different tracks ranging from the shortest (the vertical linear track) composed of four teaching sequences and four nodes to the longest (the horizontal branched track) composed of the entire vertical track plus all the remedial teaching sequences and branch nodes.

Strategy: The strategy of a contingent program is the logic of the algorithmic decision procedure used to determine which stimulus should be presented during each frame and to control the subject's track through the program. It is assumed that the computer has as data for the decision procedure: all stimuli available for presentation or a complete set of stimulus generation rules; the set of all responses permitted by the subject; a complete set of branching decisions; and a specified final performance criteria each subject is expected to meet. (Groen and Atkinson, 1966)

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